UNCLASSIFIED

AD 634 739

U. S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

AIR WARFARE RESEARCH DEPARTMENT

REPORT NO. NADC-WR-6030 NOVEMBER 1960

DEVELOPMENT OF WEAPON SYSTEM RELIABILITY GOALS FROM OPERATIONS ANALYSIS

BUREAU OF NAVAL WEAPONS
Weptask No. R520 OD 005/202 4/F018 02 003 30

This report is a reprint of a paper presented at the 4th Navy-Industry Conference on Aeronautical Material Reliability, 1-2 November 1960

PREPARED BY: L. Rogin
L. ROGIN

J. Brown
J. BROWN

APPROVED BY: W. H. Raber
W. H. RABER, Director
Air Warfare Research Department

UNCLASSIFIED

Operations analyses are normally conducted on a proposed naval weapon system in order to evaluate its anticipated performance relative to other competitive systems or to provide an indication of how well it might meet some existing operational requirement. Analytic studies are most often associated with the very early development stages of a system since their purpose is to establish the broad design goals for weapon system performance factors such as speed, endurance, payload, radar range and guidance accuracy. Reliability is one of the performance factors which is all too often omitted. Optimum values of these factors are derived as a result of processes aimed at achieving maximum system effectiveness relative to the expenditure of various available resources. In brief, we derive

- Optimum values of weapon system performance factors
  - From operating analyses
  - By maximizing:

$$\frac{\text{Effectiveness (or results obtained)}}{\text{Cost} \quad \text{(or resources used)}}$$

Following a preliminary operations analysis, which really should be conducted as an in-house study by the Navy, there are additional operations analyses generally performed by one or more representatives of outside industry. These subsequent studies often take the form of proposals by vehicle or equipment contractors for the design, development and/or manufacture of the subject system. Since these later analyses are directed at a specific set of system characteristics, they are generally more limited in overall scope than the earlier studies but at the same time they are more detailed in their treatment of the specific system characteristics.

Reliability Considerations in the Selection of a Weapons System

Although operations analysis has much to contribute in all phases of the weapon system reliability program I would like to limit this talk to considerations of reliability prior to the decision to award the contract for a given system. Our experience with operations analyses of this

weapon system planning type has convinced us that operational reliability is an extremely critical performance factor and that it can well be the determining factor in the final selection of a weapon system. Reliability considerations must be incorporated into these early operations analyses and treated in as rigorous and logical a manner as any other important weapon system design item. Maximizing system effectiveness per unit cost, in order to establish an optimum level of reliability, is visualized as a necessary step toward the development of reliability goals.

It appears logical for us to approach this problem of reliability goals from the viewpoint that operational reliability, like all other weapon system performance factors, is associated with a price of some kind. The goal we should strive to attain is maximum effectiveness (or results) for this particular expenditure of resources.

Two aspects of reliability must be considered. One phase of reliability affects the probable success of a mission once an aircraft, for an example, has taken off on its mission. A second, and equally important phase, determines the availability of the aircraft for participation in the mission in the first place. Operational reliability will be defined here as an all-inclusive term which incorporates both of these considerations. To go further into the matter of definitions, it might be well for us to discuss the effectiveness or results obtained. Since we are dealing with military systems, the results which are of interest are military in nature. In an attack system, this might be the destruction or neutralization of some enemy potential. In defense systems, the desired result may be the thwarting of an enemy's attack on us. Effectiveness must be defined very carefully since a restrictive definition can limit the scope of an analysis and important considerations leading to a valid solution may be omitted. The cost or resources term must also be defined carefully since, as indicated earlier, it represents an expenditure of some resource which does not necessarily have to be dollars. Depending on the specific situation, this resource might be some critical material, skilled personnel, elapsed time or space aboard an aircraft carrier.

The influence of weapon system operational reliability on the selection of a system design is illustrated by an abbreviated example taken from a

recent operations analysis. The problem was to determine the best gross weight for a next generation carrier-based fixed-wing aircraft for ASW. Since, for this simplified segment of the study, the aircraft speed, the equipment it carries, and the mission it is required to perform, are all fixed, the effectiveness can be measured in terms of the total number of productive flight hours per day corresponding to a carrier load of aircraft. Figure 1 shows that there were two distinct, area-dependent factors which defined the number of aircraft to be considered as a full carrier load.

Just as deck area limits the number of aircraft of a given size which can be parked on the deck, the space available for housing of air squadron personnel limits the number of maintenance and flight personnel who can be accommodated on the ship. This can be a limiting factor in the number of aircraft which can be fully utilized on the ship as indicated by the personnel curve of figure 1 which shows the maximum number of aircraft which can be utilized as a function of airplane gross weight. For vehicle gross weights greater than 45,000 lbs., the total hangar and deck area available for parking aircraft was the limiting factor For smaller vehicles, the living area available for the necessary number of squadron personnel established the limit. In either case it can be seen that space aboard the carrier meets our definition of an available resource with a definite limit. For maximum effectiveness (at least without change in carrier design), either personnel living area or aircraft parking area must be utilized to the fullest extent; however, within the ground rules of the study, neither limit can be exceeded.

Carrier deck spotting studies permitted us to establish the relationship between aircraft parking area and the limiting number of aircraft per carrier in a fairly straight-forward manner. Personnel living area, as a limit, presented us with the more difficult problem of determining the total number of squadron officers and enlisted men required per aircraft as a function of aircraft gross weight.

The final expression which was derived for living area, associated with flight crew and maintenance crew requirements, is given in the following equation.

$$A = N \left[25 (P + 1) + 390 \left(\frac{T + 2}{T + 4} \right) \right]$$

where

A = Total personnel living area required
N = Total Number of aircraft per carrier
P = Number of maintenance personnel per aircraft
T = Aircraft endurance in hours

The value of A is shown to be dependent on both aircraft endurance and maintenance manpower requirements. The relationship between endurance and gross weight was well established in terms of aircraft design items such as total fuel carried and fuel consumption rates. Our personnel living area problem thus resolved itself into a study of maintenance manpower requirements.

All aircraft had the same basic configuration and all carried the same basic electronic equipment. The single variable was vehicle gross weight and this resulted, primarily, in a variation of vehicle endurance. With major electronic sub-systems as a non-varying quantity, we took advantage of the experience gained by naval airframe contractors in the preparation of their personnel planning data reports. We compiled available equipment reliability information in terms of failures per hour of operation, per flight or per number of times turned on, as applicable. Corresponding data on repair or replacement times associated with these failures as well as routine inspection and maintenance requirements, as anticipated, provided the necessary information from which estimates of maintenance man-hours per flight-hour were derived. The following equation indicates how this maintenance term is generated, for a representative aircraft, as a result of requirements for daily maintenance , maintenance per flight and maintenance per flight hour.

$$(mmh/fh) = (9.25/T_F) + (3/T) + (5.75)$$

where

T_F = Average number of flight hours per day

T = Aircraft endurance (or flight hours per flight)

Standard naval personnel planning procedures are now employed to establish "men required per aircraft" from which the personnel living area limit of figure 1 is ultimately obtained. If effectiveness is defined, as stated earlier, in terms of the total number of productive flight hours per day per carrier load of aircraft figure 2 will show where maximum effectiveness can be expected. The uppermost curve corresponds to the aircraft parking area limit and shows that if personnel considerations could be completely neglected, a vehicle gross weight of less than 25,000 lbs. would be desirable. On the basis of original maintenance manpower requirements, we had an effectiveness limit represented by the curve for M = 1.0. M is defined as the ratio of any new set of maintenance requirements to the maintenance requirements originally used in the study. These original requirements were associated with anticipated weapon system complexity and present state-of-the-art considerations. The effect of improved reliability resulting from state-of-the-art advances or reduction in complexity is indicated in the curve for M = 0.5 which represents a 50 per cent reduction in maintenance manpower requirements. It is important to note the associated increase in effectiveness, as well as the vehicle gross weight change, for this condition. Increases in complexity and corresponding reductions in reliability would result in a limit curve, such as that for M = 1.5, with a correspondingly lower value of maximum effectiveness.

The example just discussed demonstrated how one controlling resource, personnel living area aboard an aircraft carrier, influenced the selection of an important design factor, namely, the gross weight or corresponding size of an aircraft. The importance of reliability as a performance factor was emphasized since it was from such considerations that maintenance manpower requirements were established. Manpower limits, in turn, generated weapon system effectiveness limits.

For this selected segment of a much larger operating analysis, it was shown that the selection of the best design depended upon the reliability which could be expected.

System Effectiveness

Analyses should be run to optimize the complexity of the weapon system, the number of aircraft covering a given station, the number of missions between inspections, and the cost devoted to increasing system reliability. In the broadest sense the reliability goals, which we are seeking through operations analysis, are those which yield the greatest value of system effectiveness considering all critical resources which might be expended in their attainment. Converting all such resources into a common denominator, if at all possible in actual practice, makes a summary of this presentation somewhat simpler. Let us assume that we can take "dollars" as this normalized resource. Figure 3 is a graphic representation of expenditures for a system. The upper line represents the funds available for the development and production of a weapon system. Expenditures for increasing reliability of the system reduce the amount available for producing the vehicles and equipment which make up the system. This is shown by the reliability-cost curve, of increasing slope as reliability improves. The military effectiveness of the system provided by the given expenditure of funds is shown by the third curve. Military effectiveness increases with moderate expenditures for reliability, until a maximum is reached. If we spend too much for increased reliability we will not have enough left to procure the end product in adequate quantities and our system effectiveness will be reduced. Spending less than our operations analyses tell us to spend for reliability will permit us to buy a greater number of less reliable equipments but once again, this will tend to reduce our overall weapon system effectiveness.

We have discussed the use of operations analysis as a means for deciding what realistic reliability goals should be. The methods will be most effective if used both in the early studies of a new system and in the preparation of proposals by bidders. It is to be expected that prospective contractors can be in a position to make the best estimates of the state of the art of reliability and the costs of attaining the higher

levels. By including such studies in their proposals, they can assist in establishing the reliability goals to be expected in the performance of the contract.

The essential point which this talk is intended to make is that the reliability goal which operations analysis will develop is not maximum reliability but is, rather, that reliability which produces the maximum military effectiveness for the resources expended.

Acceptance of the idea that this should be the objective of such analyses suggests that reliability requirements incorporated in engineering procurement specifications would have several distinct characteristics:

First - They would stem from studies performed by the Navy and the contractor during the preparation of a proposal and would be uniquely related to other characteristics being provided in the specific weapon system design.

Second - They would reflect the designer's assessment of the inherent reliability levels his organization could be expected to deliver in the aircraft and its sub-systems assuming fiscal support of an engineering reliability program which the organization would define and price.

Third - They would reflect the assumption that the Navy and the contractor would be taking related and coordinated action in areas other than engineering, so that the inherent reliability of the weapon system, as such, would be matched to use reliability factors (e.g. personnel planning and training) so as to result in achieving the net predicted operational effectiveness.

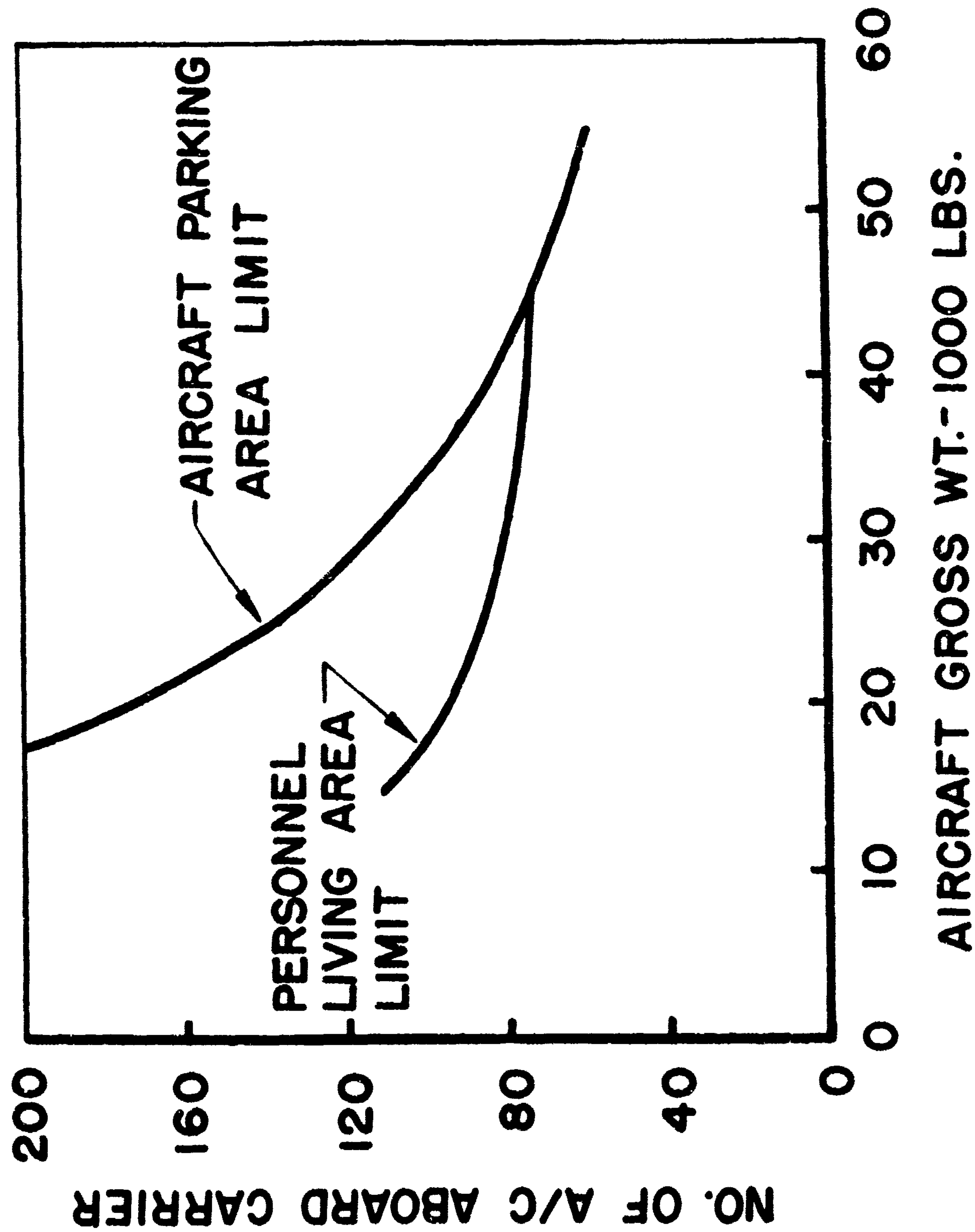

Figure 1. Limiting Numbers of Aircraft Aboard the Carrier

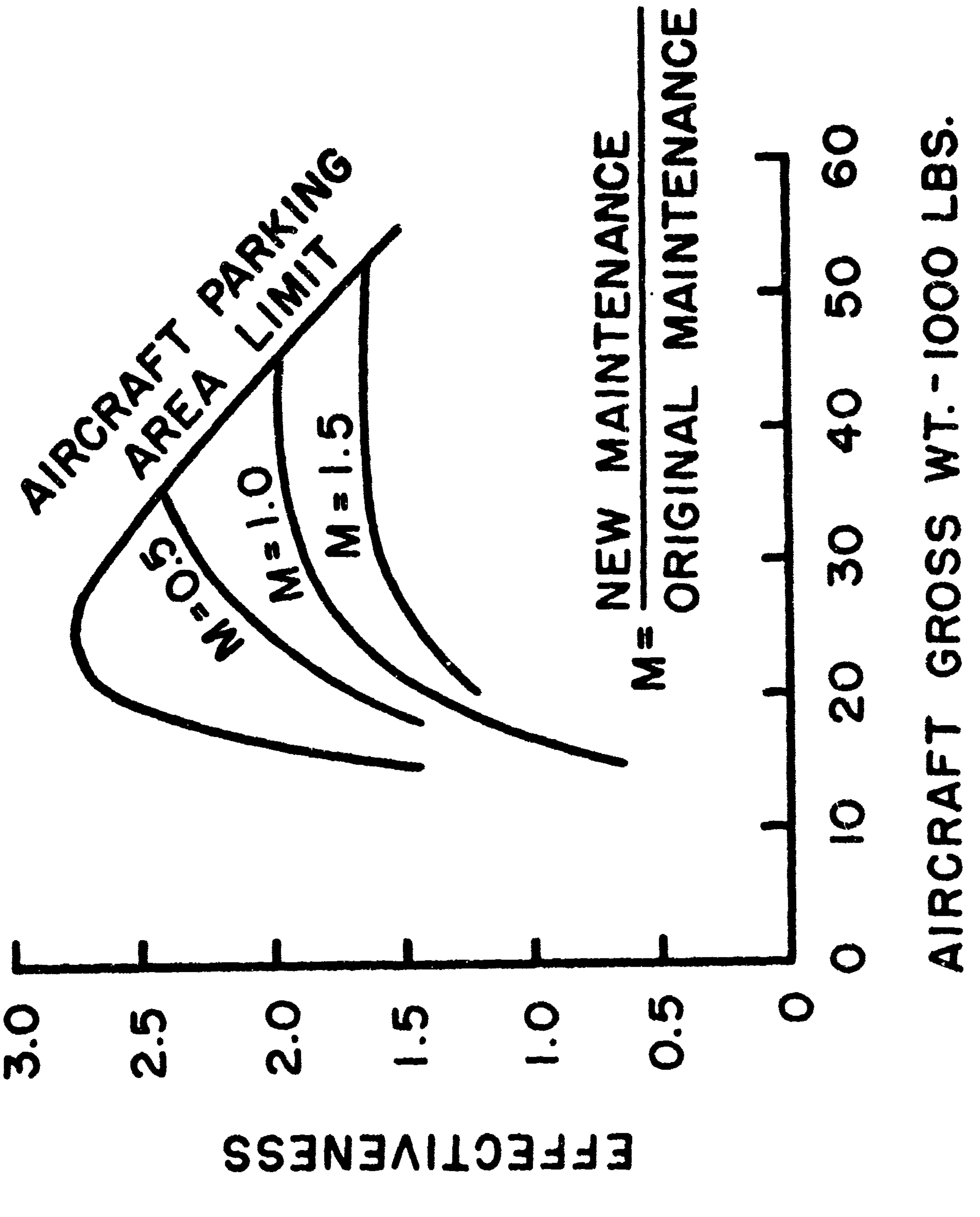

Figure 2. Aircraft Gross Weight and Maximum Effectiveness

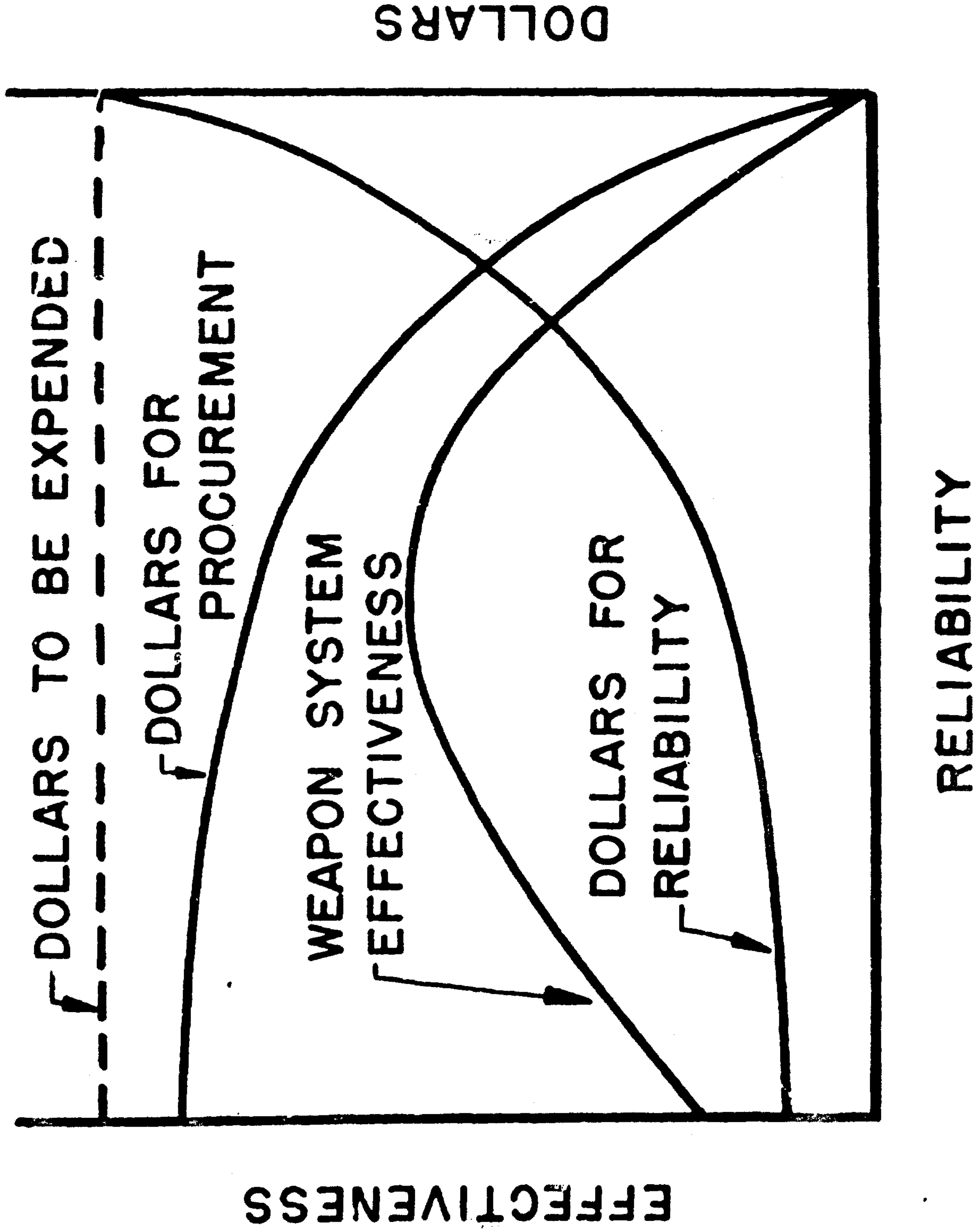

Figure 3. Effectiveness for Varying Reliability Expenditures